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Cooperative Opportunistic Large Array Approach for Cognitive Radio Networks

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Abstract— **Cognitive Radio (CR) seems to be a promising solution to the radio spectrum congestion problem by opportunistic uses of the spectral holes to achieve efficient use of the frequency resource by allowing the coexistence of licensed (primary) and unlicensed (secondary) users in the same bandwidth. According to the cooperative wireless communication (CWC) concept the active nodes may increase their effective QoS via cooperation. For cognitive radio networks, sharing of primary user's spectrum by secondary user is possible only when the QoS of the primary system is guaranteed. Cooperative diversity is a strong technique which can provide the maximum throughputs. Cooperative Opportunistic Large Array (OLA) algorithms can improve the reliability as well as the energy efficiency of the communication. Power and diversity gains can be exploited with the help of cooperative transmission in the cognitive radio. In this paper, the novel cooperative OLA approach for Cognitive Radio Networks (CRN) is proposed, which is proved to be energy efficient and scalable. With the help of OLAs, the cognitive network can be built without GPS.**

Keywords- Cooperative wireless communication, opportunistic large arrays, cognitive radio network, wireless sensor networks.

I. INTRODUCTION

The emergence of new wireless technologies has created huge demand of radio spectrum. The radio spectrum is a scarce natural resource. Due to the limitations of radio spectrum it becomes obvious that the present fixed frequency allocation schemes cannot accommodate the new emerging multimedia technologies. The actual measurement of radio spectrum utilization clearly shows that the licensed radio spectrum is underutilized continuously across time and space [1]. As a result innovative techniques which can offer new approaches of exploiting the available radio spectrum are needed. Cognitive Radio (CR) seems to be a promising solution to the radio spectrum congestion problem by opportunistic uses of the spectral holes [2].

The cooperative wireless communication (CWC) concept is more applicable to wireless sensor networks and Cognitive ad-hoc networks than that of cellular networks. In cooperative communication, the information overheard by neighboring nodes is intelligently used to provide the healthy communication between a source and the destination called as sink. In CWC, several nodes work together to form a virtual array. The overheard information by each neighboring node or relay is transmitted towards the sink concurrently. The cooperation from the network nodes that otherwise do not directly contribute in the transmission is intelligently utilized in CWC. The sink node or destination receives numerous editions of the message from the source, and relay(s) and it estimates these inputs to obtain the transmitted data reliably with higher data rates. CWC has following advantages [3]:

- Higher reliability: lower error probability with more throughput
- Reduced transmitter power with less interference
- Opportunistic use and reorganization of the network with increased energy efficiency and higher spatial diversity.
- Cooperative transmission assures remarkable improvements in overall sturdiness of the network and network throughput. It also makes sure a noteworthy reduction in interferences and different delays.
- Coverage range extension and resistance to large scale shadowing is the beauty of CWC.

For improvement in the QoS of CRN, CWC approach may be applied. There are two main cooperative approaches towards CR viz. Commons Model and Property Rights Model. In commons model, primary terminals are unaware to the presence of secondary users, thus behaving as if no secondary activity was present. Instead, secondary users sense the radio environment for finding out spectrum holes and then take advantage of the detected transmission opportunities. For the property rights model, the primary nodes may accept to lease their bandwidth for a fraction of time, in exchange for the concession, they benefit from the superior QoS in terms of rate of outage probability and improvement in energy savings [4] [5]. Cooperative relaying of primary packets through secondary nodes is proved to be a promising technique to improve the secondary throughput by utilizing the idle periods of the primary nodes.

An opportunistic large array (OLA) is a group of forwarding nodes that operate without any mutual coordination, but naturally fire together in response received from a single source or other OLA [5]. These OLAs do not need location information for routing. Due to no need of addressing, the protocol becomes scalable with node density. Not needing location knowledge for routing makes the protocol suitable for applications where location information is either not available or too expensive or energy consuming to exploit

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[6]. With the help of OLAs, the cognitive network can be built without GPS.

A cognitive radio adapts its services according to the changes in its surrounding, due to which, spectrum sensing has become an important requirement for the realization of CR networks [8]. The major necessary functionalities for spectrum sensing in cognitive radio ad hoc networks are as follows:

- Primary User (PU) Detection: the CR node continuously monitors and analyzes its local radio environment, for determining holes in the spectrum.
- Cooperation: the observed information in each CR node is exchanged with its neighboring network nodes for the improvement in sensing accuracy in case of hidden node problems.
- Sensing control: it enables each CR node to perform its sensing operations adaptively to the dynamic radio environment. Also, it coordinates the sensing operations of the CR nodes and its neighbors in a distributed manner, which prevents false alarms in cooperative sensing.

Opportunistic Large Array (OLA) is nothing but a cluster of network nodes which use active scattering mechanism in response to the signal of the source. The intermediate nodes opportunistically relay the messages from the leader to the sink. Either secondary users or combination of primary as well as secondary users can form OLAs for the good coordination among network entities. The proposed OLA approach is as shown in fig. 1 below.

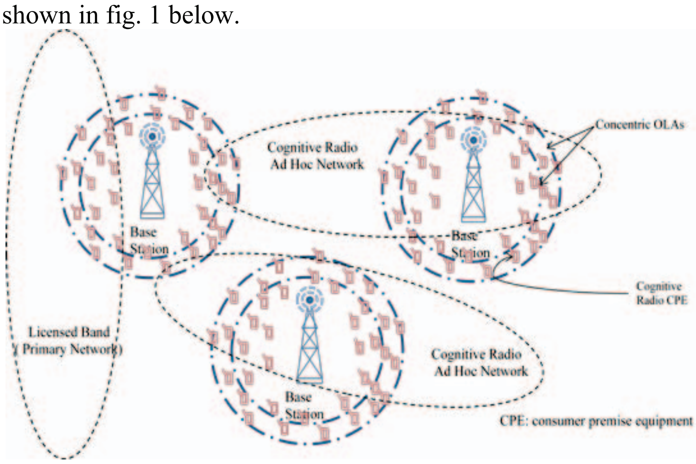

Fig.1. Proposed OLA Approach for Cognitive Radio Networks

Cognitive relaying concept is employed through the cooperative OLA model, in which relaying of primary traffic takes place through secondary users. In this scenario, supporting the primary traffic to increase its throughput results in a decreased transmission time of the primary, which in turn leads to more transmission opportunities for the secondary. For cooperative transmission, OLA selects the nodes which has the received signal SNR above some threshold figure and since the resonance generated by relay nodes carries the actual messages to the desired sinks without causing interference. For the abolition of the routing and multiple access overheads, OLA is a competent physical layer broadcasting algorithm. Multiple clusters of ad hoc wireless nodes can form a multi-OLA system, constructing a multiple access system with the cluster of nodes acting as a team through cooperative transmission rather than transmitting independent data from each node. OLAs can either be with regenerative or non-regenerative. OLA utilizes the cooperative transmission of the Ad Hoc network nodes to reach back a far distant node or sink [7]. OLA can apply either to existing or newly designed modulation techniques that exploit the positioning diversity of the ad hoc radio nodes. OLA can also be easily built on top of any existing ad hoc systems without changing their original structure [9].

II. SYSTEM MODEL

The consumer radio devices which are half-duplex in nature are assumed to be uniformly and randomly distributed over a continuous area with average density ρ. As in [9], the deterministic model is assumed, which means that the power received at a Consumer Premise Equipment (CPE) is the sums of powers form each of the CPE. In this model, the network node transmissions are orthogonal. It is assumed that a CPE can decode and forward a message without error when it's Signal to Noise ratio (SNR) is greater than or equal to modulation-dependent threshold λ_d [9]. Due to noise variance assumption of unity, SNR criterion is transformed into received power criteria and λ_d becomes a power threshold. Let P_s be the source transmit power and the relay transmit power be denoted by P_r, and the relay transmit power per unit area be denoted by $P_r = \rho\ P_r$. The assumed continuum model is as shown in Fig.2. Suppose that every transmission with power P is received with power P.$l(d)$=P/d^2 at distance d, where $l(.)$ is a path loss attenuation function, which in general is assumed to be continuous and non-increasing. For the ease of presentation, a bounded network is assumed. The aggregate path loss from a circular disc of radius x_0 at an arbitrary distance p > x_0 from the source is given by,

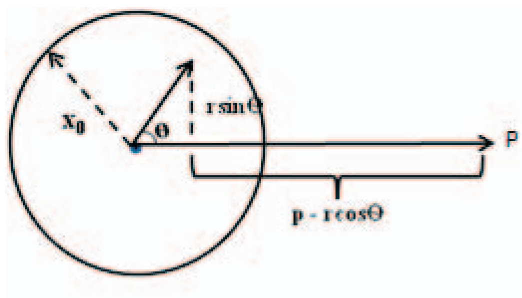

Fig.2. Illustration of $f(x_0, p)$

$$f(x_0, p) = \int_0^{x0}\int_0^{2\pi} l(p - rcos(\theta), rsin(\theta))\, rdrd\theta \qquad (1)$$

$$= \pi \ln \frac{p^2}{|p^2 - x_0^2|}$$

Let r_0, r_1, ……. denote the solution of the recursive formula.

$$f(r_{k-1}, r_k) - f(r_{k-2}, r_k) = \frac{\lambda}{p_r}, \ k = 2,3,4 \ldots \qquad (2)$$

with initial conditions $r_0=0$, $r_1 = l^{(-1)}(\frac{\lambda}{\overline{P_r}})$. If the solution of above equation exists then each level set is a disk shaped region with inner and outer radii given by r_{k-1} and r_k respectively. Hence $\overline{P_r}\,[f\,(r_{k-1}, r_k) - f\,(r_{k-2}, r_k)]$ is the received power at a node with distance r_k from the source, when the disc between r_{k-2} and r_{k-1} transmits.

Theorem: If $\mu \triangleq e^{(\lambda/\pi\rho P_r)}$ [9] and $\mu > 2$,
then

$$r_k = \sqrt{\frac{P_s(\mu-1)}{\lambda(\mu-2)}}\left(1 - \frac{1}{(\mu-1)^k}\right) \tag{3}$$

and

$$\lim_{k\to\infty} r_k = r_\infty = \sqrt{\frac{P_s(\mu-1)}{\lambda(\mu-2)}} \tag{4}$$

For ($\mu \le 2$), the broadcast reaches to the whole network i.e. $lim_{k\to\infty} r_k = \infty$.

For ($\mu > 2$), the total area reached by the broadcast is limited i.e. $r_k < r_{total}$.

Instead of infinite radius, we are considering some practical scenarios where the radius is limited. For wireless LAN, the maximum radius covered is found to be approximately 100 meters. The cellular coverage areas for different cell structures are as follows:

1. Pico cells: 100m x 100m
2. Micro cells: 1000m x 1000m
3. Macro cells: Up to several kilometers.

Minimum node density requirement for particular transmission is obtained with the help of following equations.

$$\frac{\lambda}{\rho P_r \pi} > ln2$$

$$\rho < \frac{\lambda}{\pi(ln2)P_r}$$

$$\frac{N_{total}}{\pi r_{total}^2} \ge \frac{\lambda}{\pi(ln2)P_r} \tag{5}$$

where N_{total} is the maximum number of active nodes utilized for particular cooperative transmission for the radius r_{total} as shown in fig.3 below.

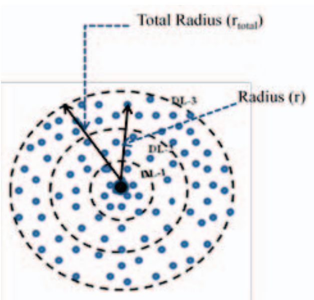

Fig.3. Proposed OLA structure for Numerical Analysis

Also for ($\mu > 2$), from eq. (3), the critical density could be obtained as follows,

$$\rho_{critical} = \frac{\lambda}{P_r \pi \ln\left(\frac{2\lambda r^2 - P_s}{\lambda r^2 - P_s}\right)} \tag{6}$$

If the network's active node density $\boldsymbol{\rho}$ is smaller than $\boldsymbol{\rho_{critical}}$ then the signal transmitted from source will not reach to the destination receiver.

Out of total radio nodes, the radio nodes utilized for particular cooperative transmission can be calculated with the help of plot in between total nodes in the radio network (N) and radius till that level (r).

The Fraction of Energy Saving (FES) with the OLA approach can be written as a ratio of

$$\text{FES} = 1 - \frac{\begin{matrix} number\ \ of\ active\ radio\ nodes\ utilized \\ for\ cooperative\ \ transmission \end{matrix}}{\begin{matrix} Total\ number\ \ of\ nodes \\ in\ the\ OLA\ network \end{matrix}} \tag{7}$$

III. SIMULATION RESULTS

As seen from Fig.3, for lower threshold values like lambda=0.5, maximum energy savings are observed. Also for threshold values of lambda=1.5, considerable energy savings are observed.

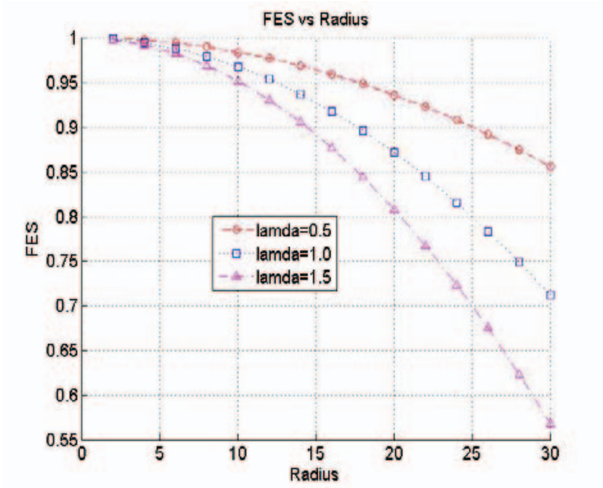

Fig. 3. Fraction of Energy Saving (FES) as a function of Radius and SNR threshold

From Fig. 4, it is observed that after certain radius value, the network node density seems to be almost constant. This indicates that for particular node density, the broadcast beyond certain radius is meaningless.

For lower SNR threshold values, considerable energy savings are observed from Fig. 5. The relationship between number of nodes participating for particular transmission and radius is interesting. From Fig. 6, for lambda=0.5 and radius=30, the maximum node participation is around 400 to 420.

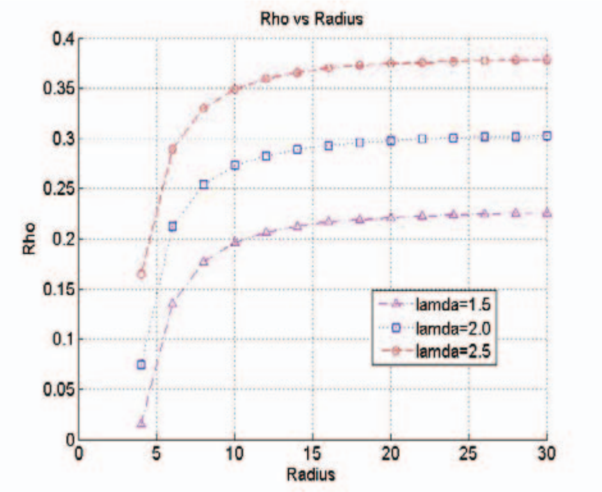

Fig.4. Radio node density as a function of Radius and SNR threshold

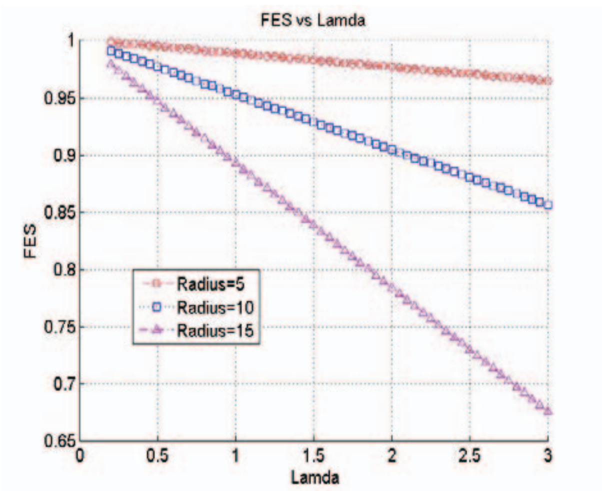

Fig. 5. Fraction of Energy Saving (FES) as a function of SNR threshold and Radius

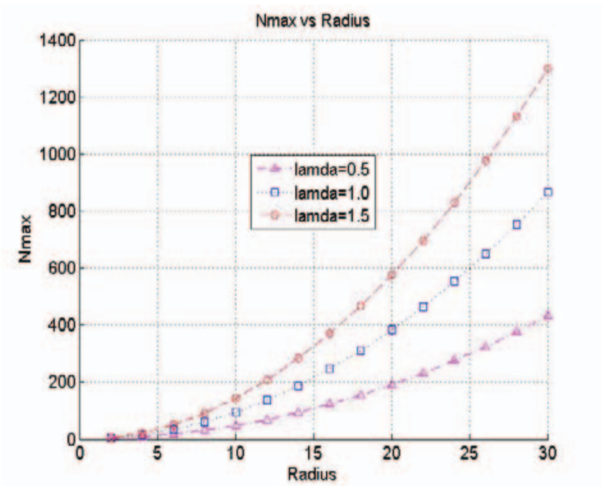

Fig. 6. Nodes participated in cooperative communication as a function of Radius and SNR threshold

IV. CONCLUSIONS

This paper proposes a novel energy-efficient opportunistic large array approach for CRNs. The uniqueness of this algorithm is that node location information and high source transmit power for data are not needed. This kind of mechanism can be applied to cognitive applications like wireless LAN, cellular pico-cells in hot spot situations and Bluetooth. For limited radii broadcasting, the minimum energy consumption by the network has been achieved. 57% of the energy savings are observed for the radius of 30 meters. The OLA approach considered here utilizes spread spectrum coding mechanism with RAKE receiver. This work will be extended further with orthogonal frequency division multiplexing (OFDM) technique.

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